Numerical Study of Urban Heat Waves and Mitigation Effects of Cool Roof in Chongqing City

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- Chongqing thermal environment and local circulation characteristics
- Impacts of AC on urban temperature
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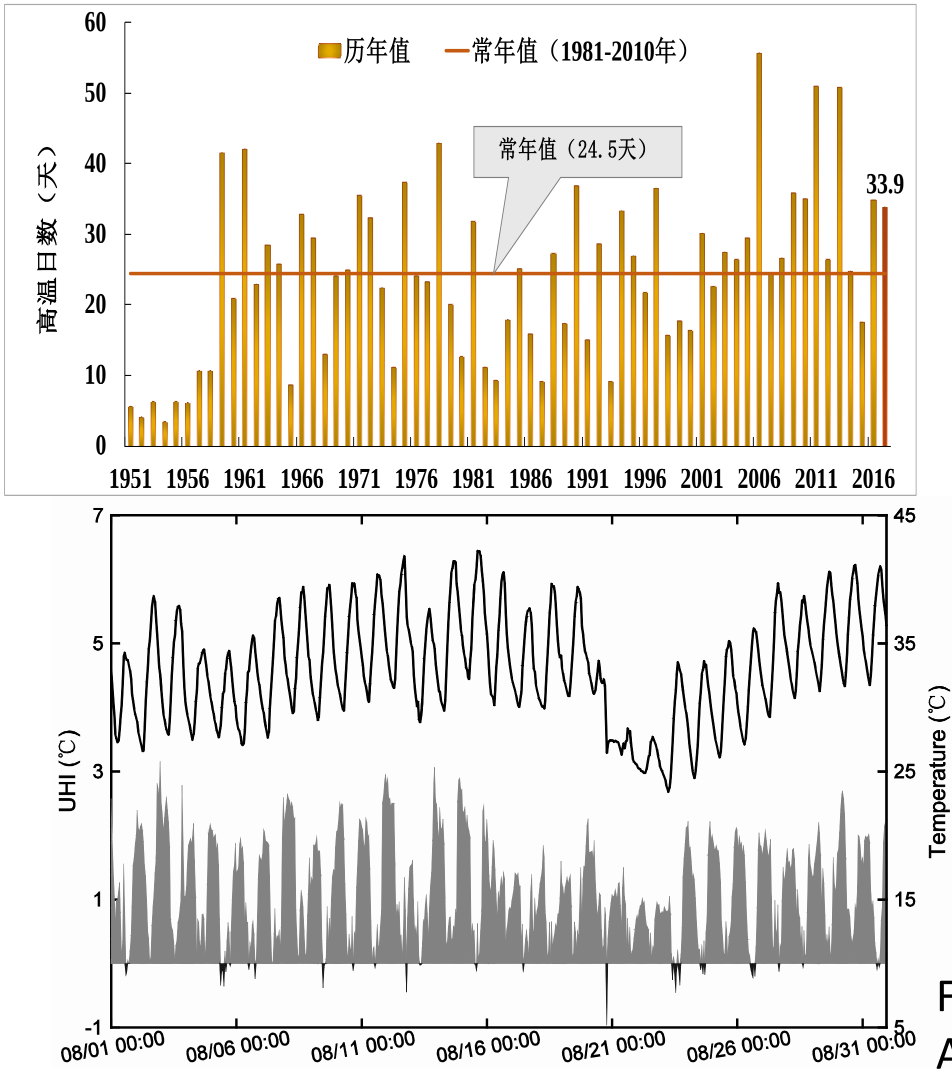
Introduction

- More extreme heat wave events occurred during last 30 years (IPCC AR5).
- Urban Heat Island (UHI) , caused by large amount of heat generated from urban complex structures and anthropogenic heat sources, is the main reason of citywide high temperature events.
- Chongqing is one of the regions with high incidence of high-temperature heat waves. Compared to other cities, Chongqing has a complex terrain and dense urban population and buildings.

Purpose

- Validate the applicability of BEP+BEM urban canopy scheme in Chongqing;
- Analyze characteristics of Chongqing urban Heat Island;
- Analyze the effect of anthropogenic heat emitted from AC on the formation of high temperatures;
- Analyze mitigation effect of cool roof.

Data and Methods



54 days

$T_{day} > 35$℃ in 2006

During Aug. 14th –15th

$T_{max} > 41$℃

$UHI \sim 3$℃

Fig.1 High temperature days since 1951 (a)
Average urban temp. and UHI in Aug. 2006 (b)

Model configuration

Simulation case:

1. URBAN
2. NOURBAN
3. AC_OFF, AC_300
4. REF_0.8, REF_0.6, REF_0.4

Domain number	1	2	3	4
Simulation period	2006 Aug. 13^{th} 20:00 -- 2006 Aug. 16^{th} 08:00 (BJT)			
Initial Met. Field	NCEP FNL (1° resolution)			
Landuse	USGS-24 cat			High-resolution GIS data
Vertical layers	36 layers, of which there are 21 layers below 2km.			
Horizontal nest	219 × 146	199 × 199	241 × 241	163 × 172
Horizontal resolution	9 km	3 km	1 km	333.33 m
Other parameters	Micro physics : WSM5			
	Longwave radiation : RRTM			
	Shortwave radiation : Dudhia			
	PBL : Boulac / Monin-Obukhov (Janjic Eta)			
	Urban canopy : Multi-layer, Building Environment Model (BEM) scheme			
	Surface : unified Noah land-surface model			

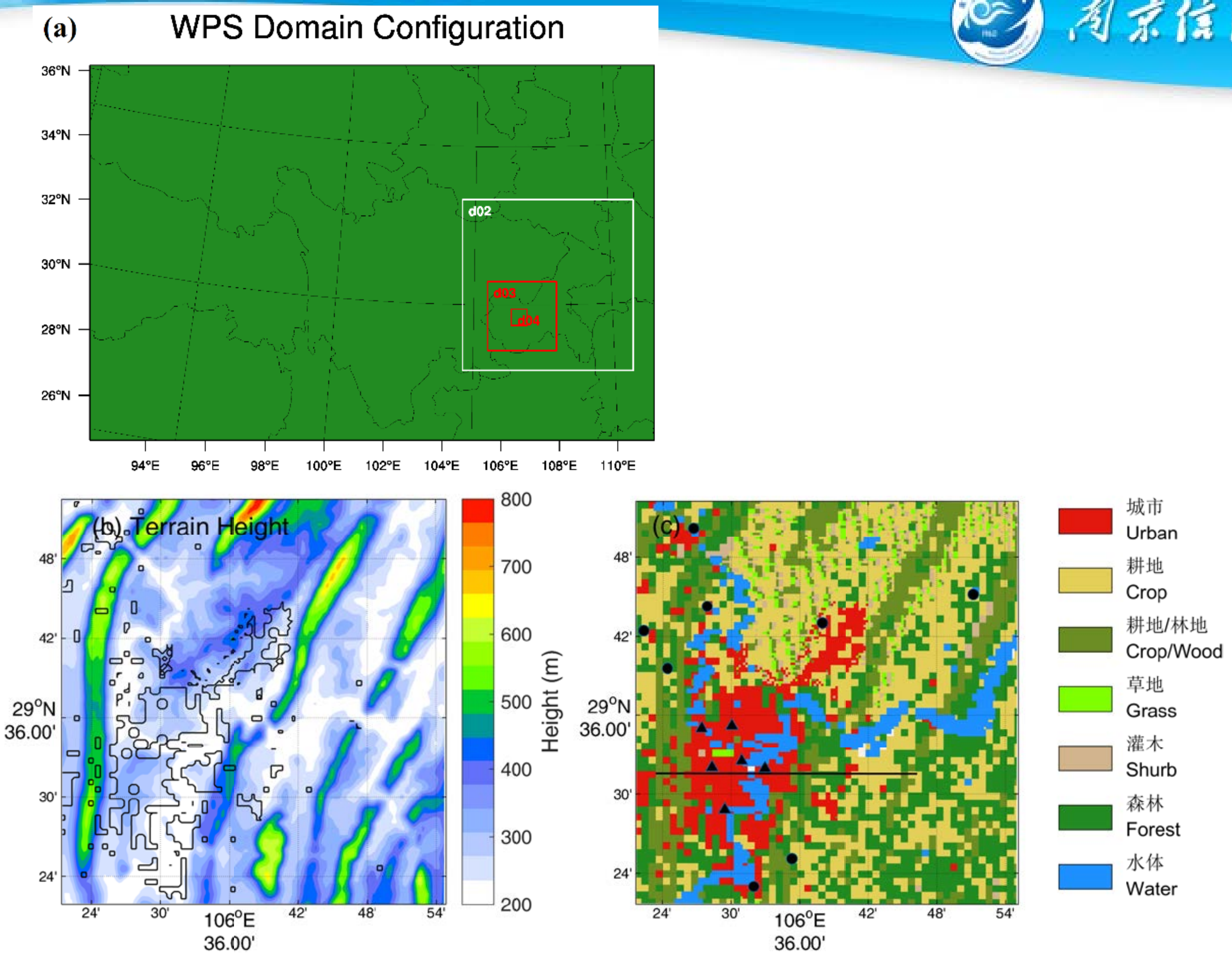
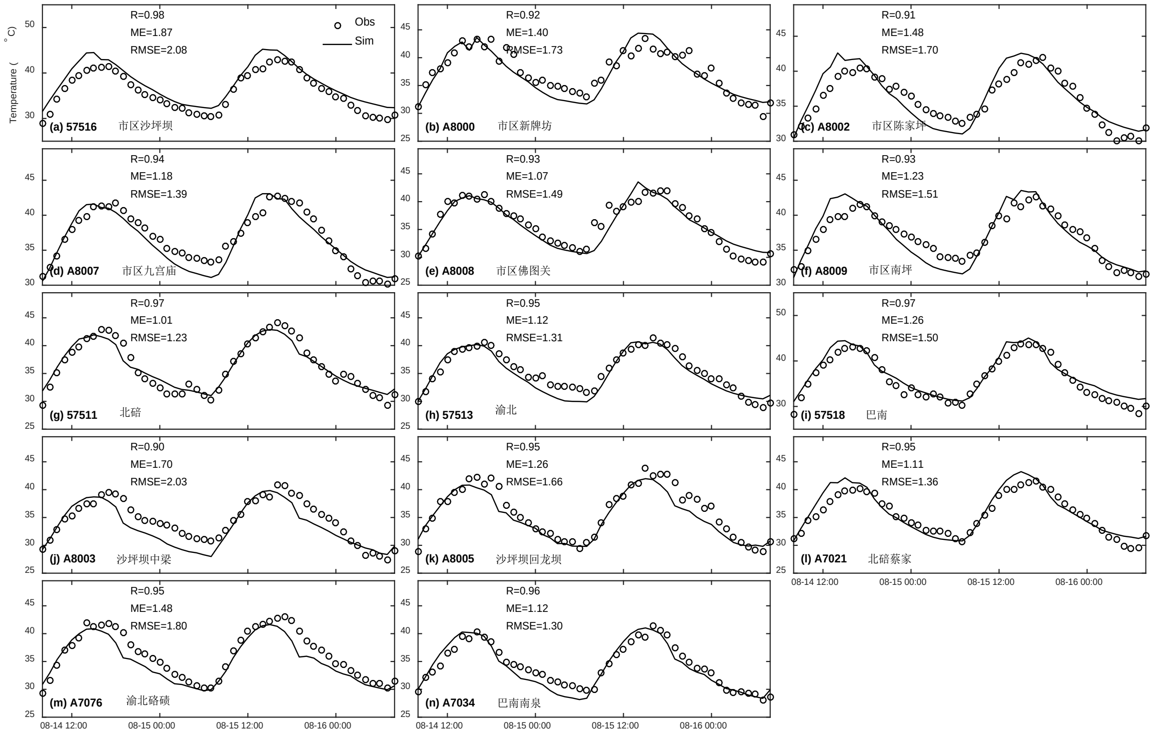


Fig 2. Simulation domain (a), terrain height (b) and land use distribution (c) of the most inner domain

Simulation validation

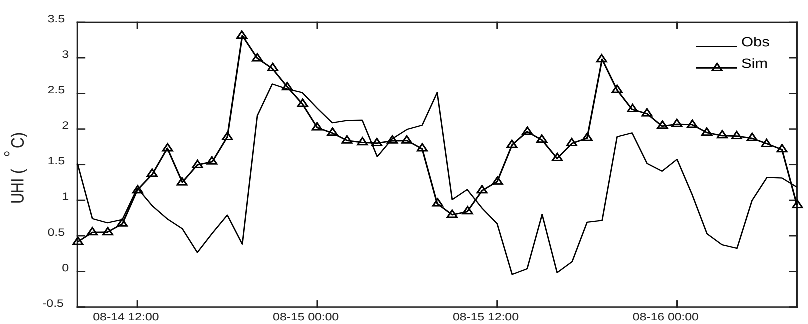


Average

$$R > 0.90$$

$$ME < 1.3°C$$

$$RMSE < 2°C$$



$$T_{2m} = Ts - \frac{H}{\rho c_p C_H}$$

$$C_H = \frac{k \times u_{*,2m}}{\ln\left(\frac{2m}{z_{0,T}}\right) - \psi_H}$$

Fig.3 Observed and simulated 2m temperature of 14 sites (a); Observed and simulated UHI (b)

Thermal environment and local circulation characteristics

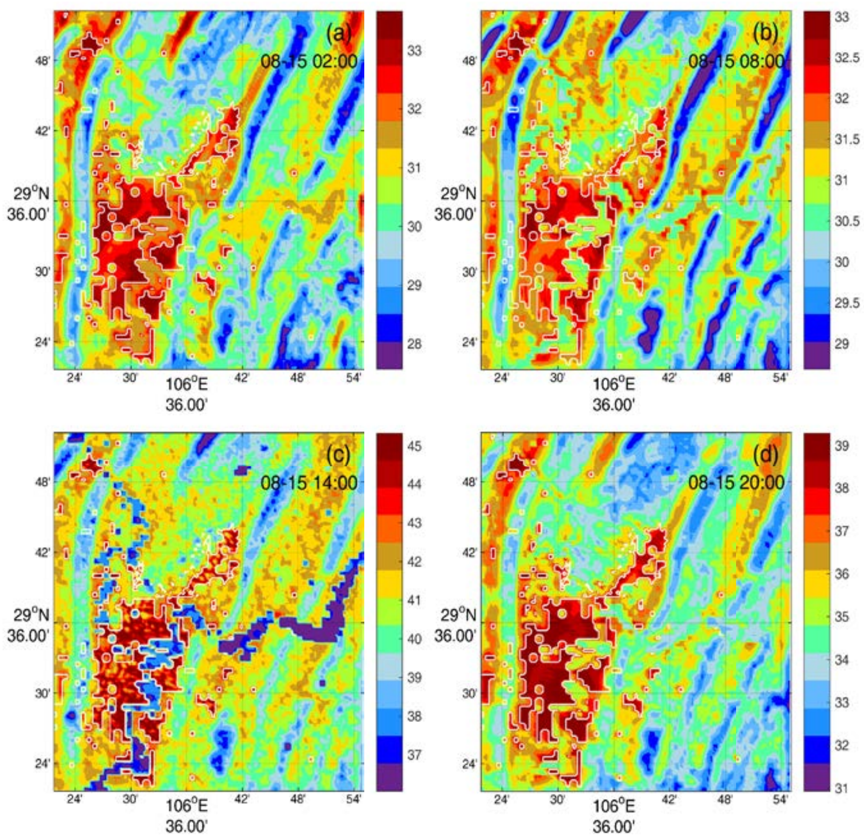


Fig.4 URBAN case simulated 2m temperature (unit ℃) distribution in Aug. 15th 2006

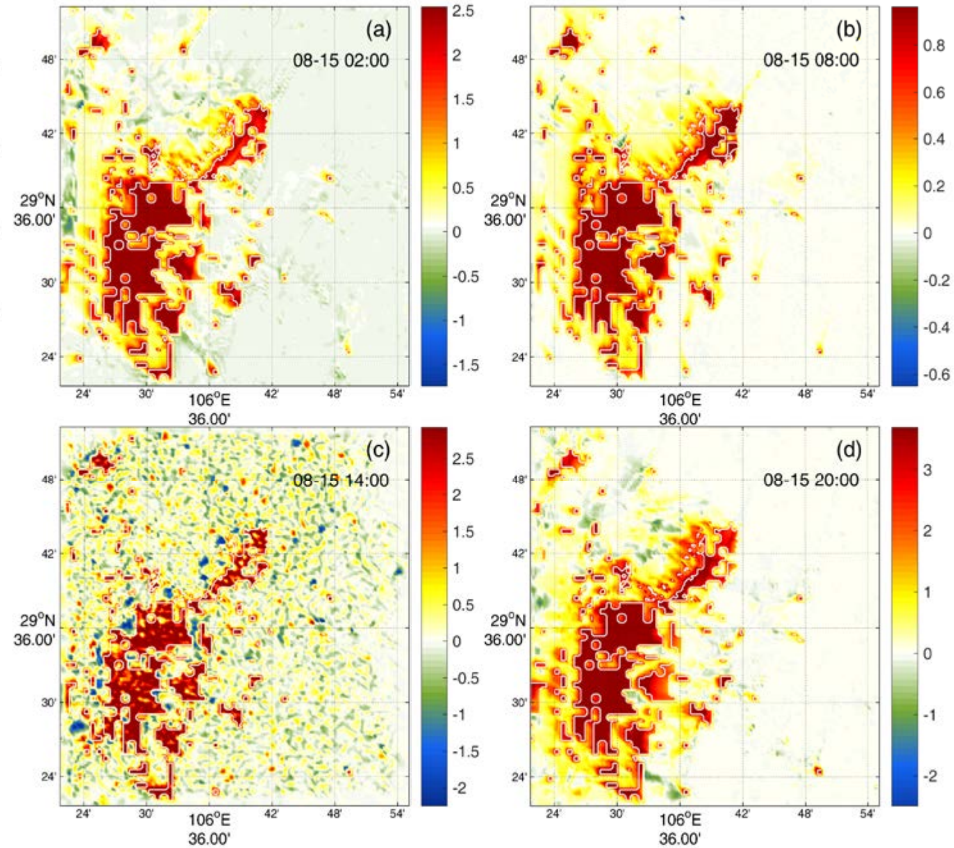


Fig5. URBAN—NOURBAN 2m temperature (unit K) difference distribution in Aug. 15th 2006

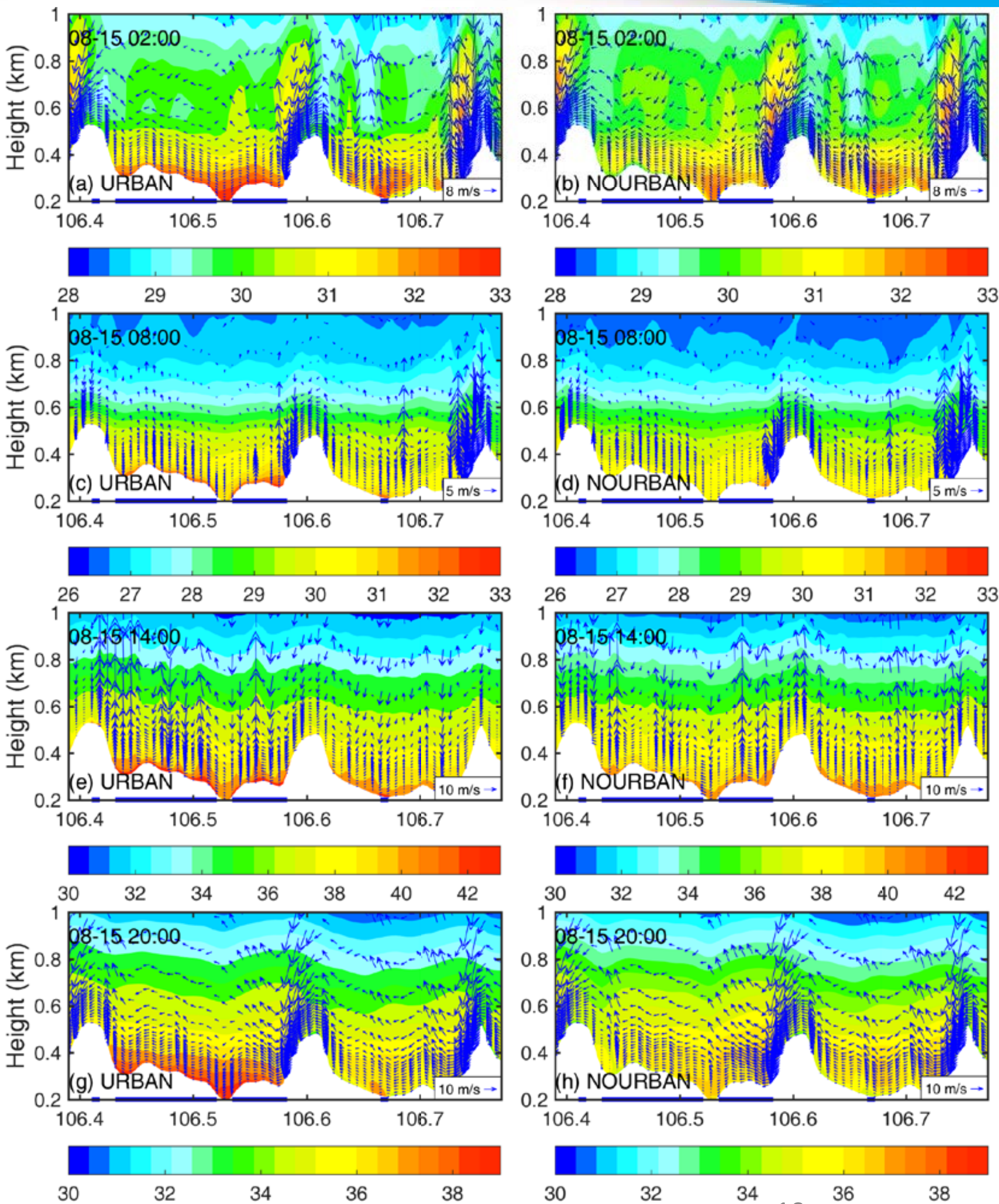


Fig6. Vertical distribution of URBAN case and NOURBAN case temperature (unit ℃) in Aug. 15th 2006

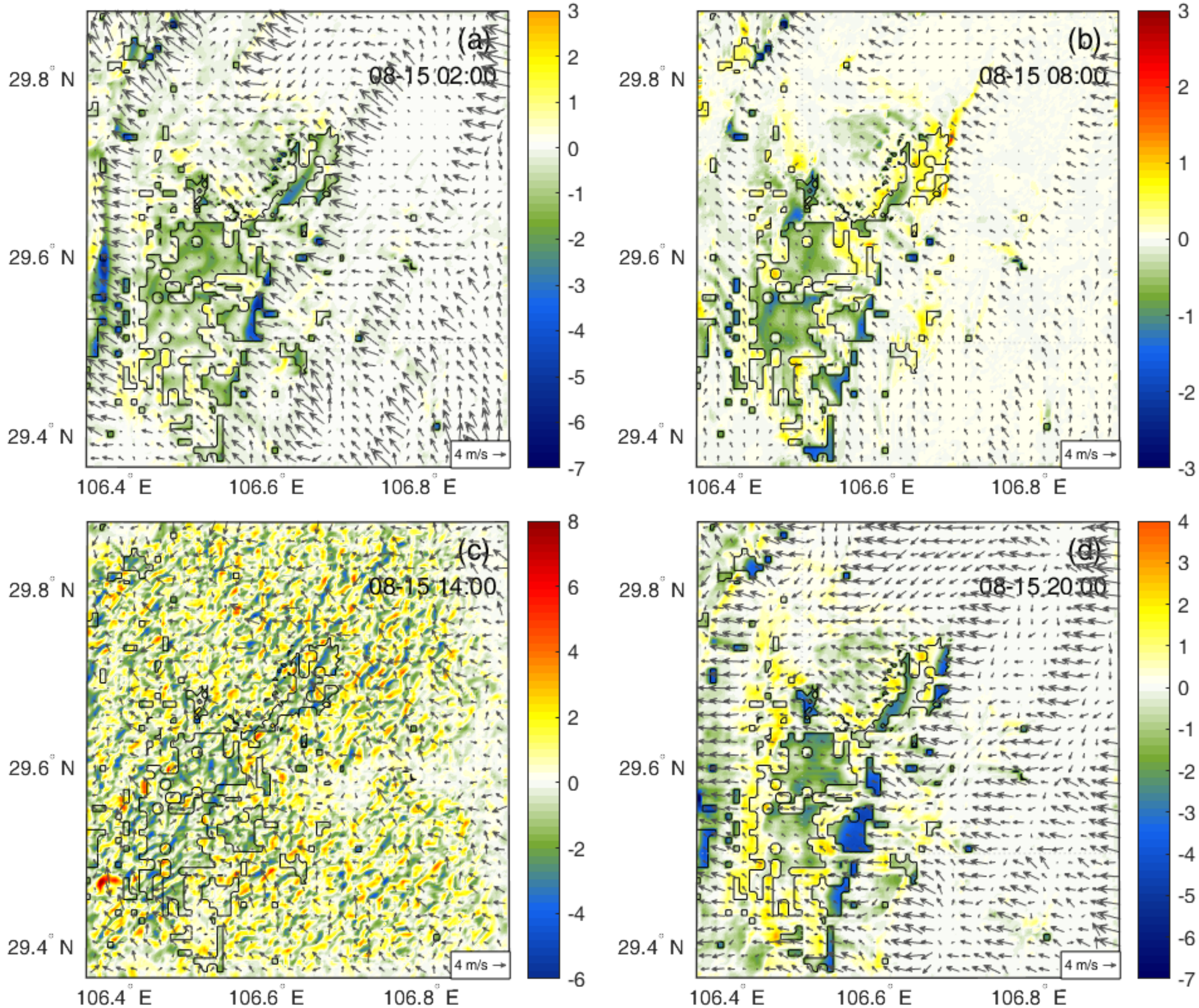


Fig.7 URBAN—NOURBAN horizontal wind speed (unit m/s) difference distribution

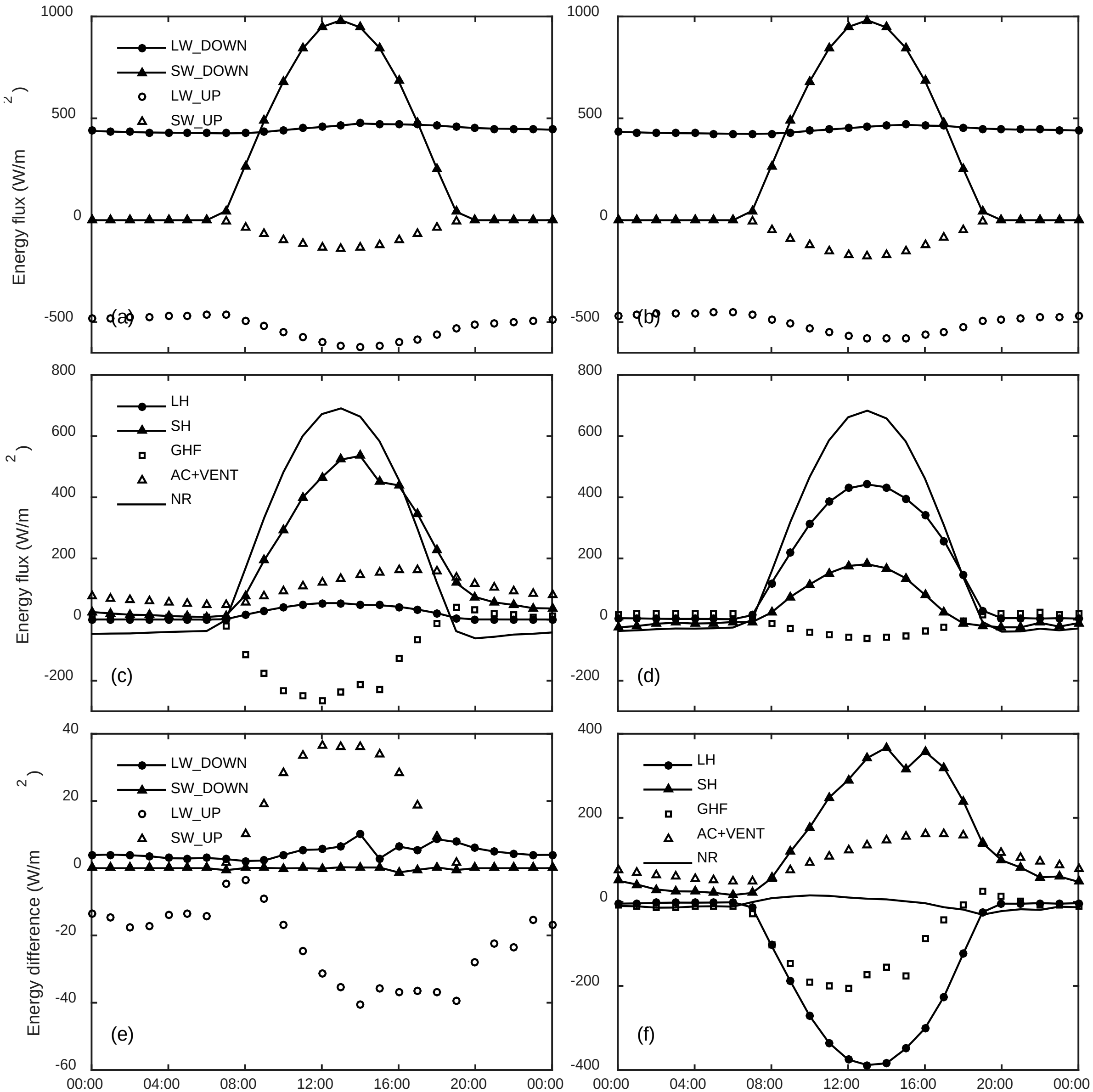


Fig.8 Radiation and energy flux of urban area in Aug. 15th 2006

Impacts of AC on urban temperature

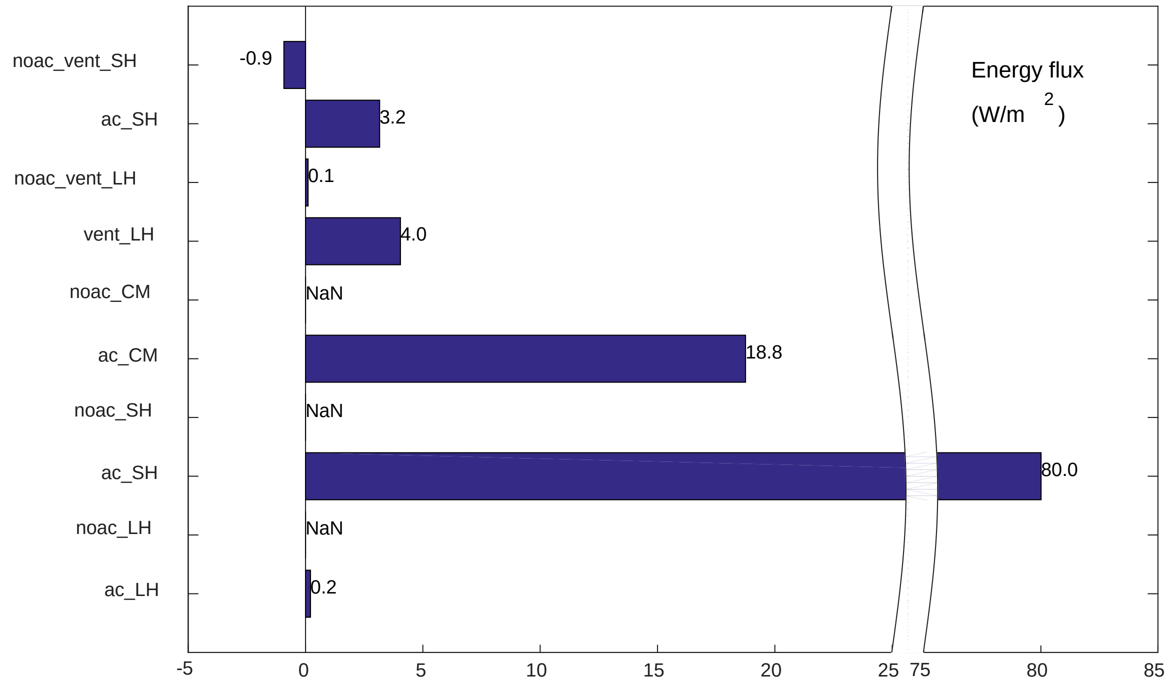


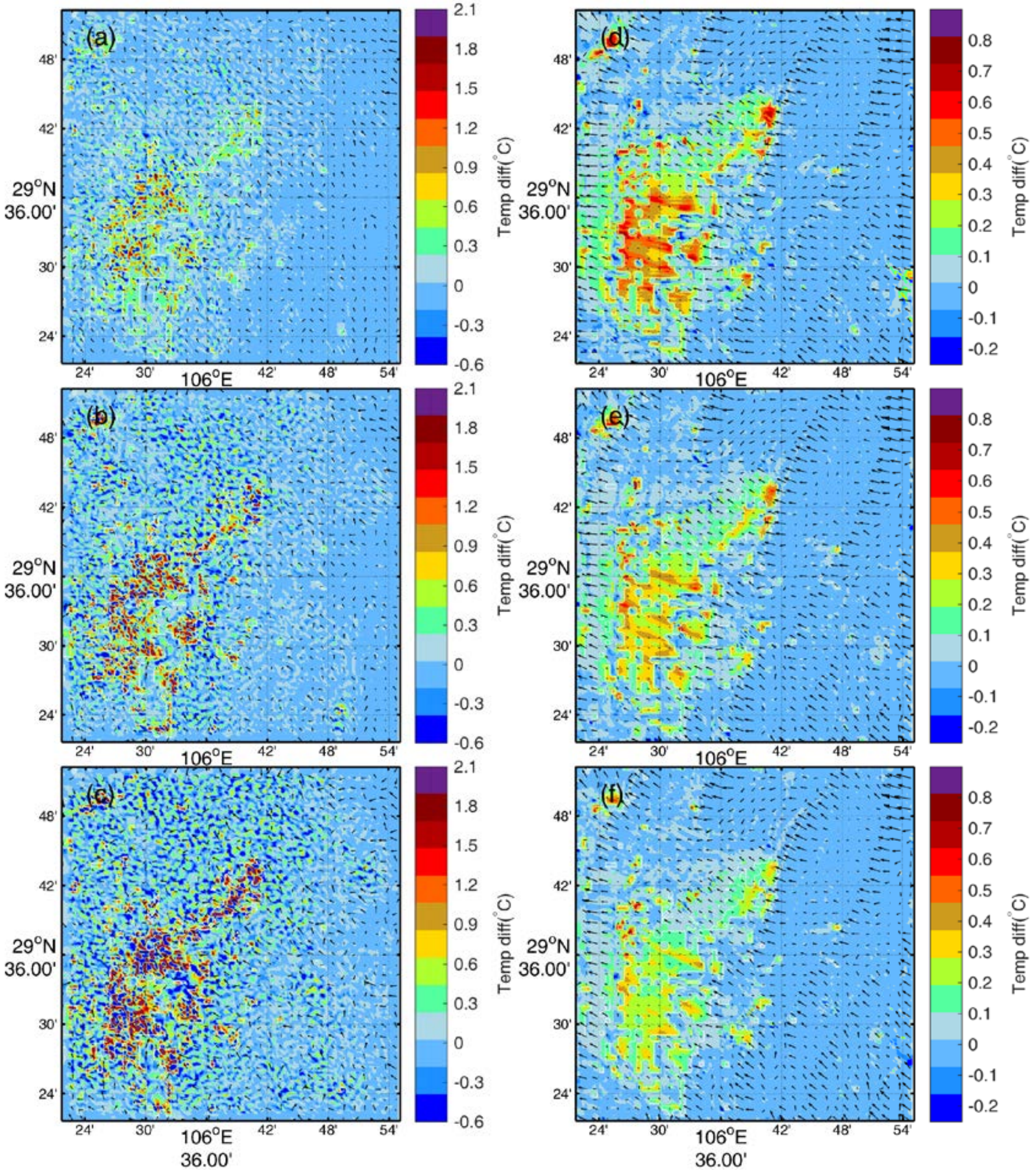
Fig.9 Average energy exchange released by AC between inner and outside room simulated by BEM scheme

Total average energy released by AC:

$$106.2W/m^2$$

Compared to max sensible heat simulated:

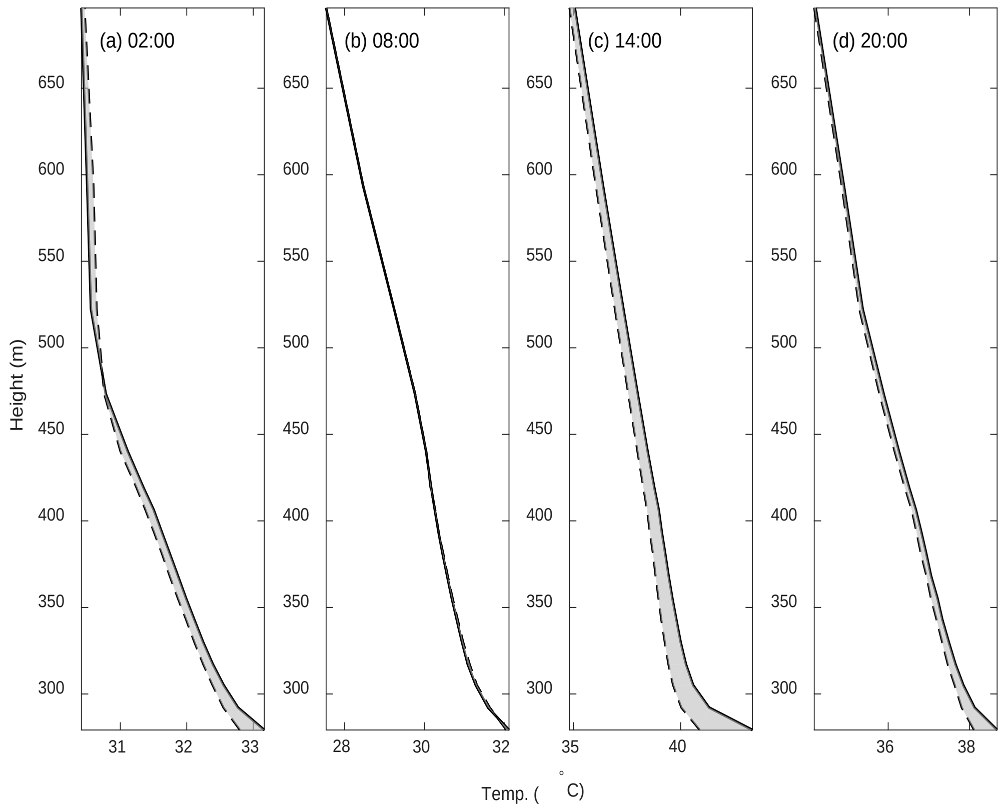
$$\sim 500W/m^2$$



Average temp. diff is ~0.5℃.

Compared to average temp. diff caused by UHI (~2℃)

Fig.10 Temperature difference between URBAN & AC_OFF in different time on Aug.15th



Strong turbulence in 14:00 leads to a good mixing of temp.

Fig.11 Simulated Temp. profile of urban site Nanping in Aug. 15th

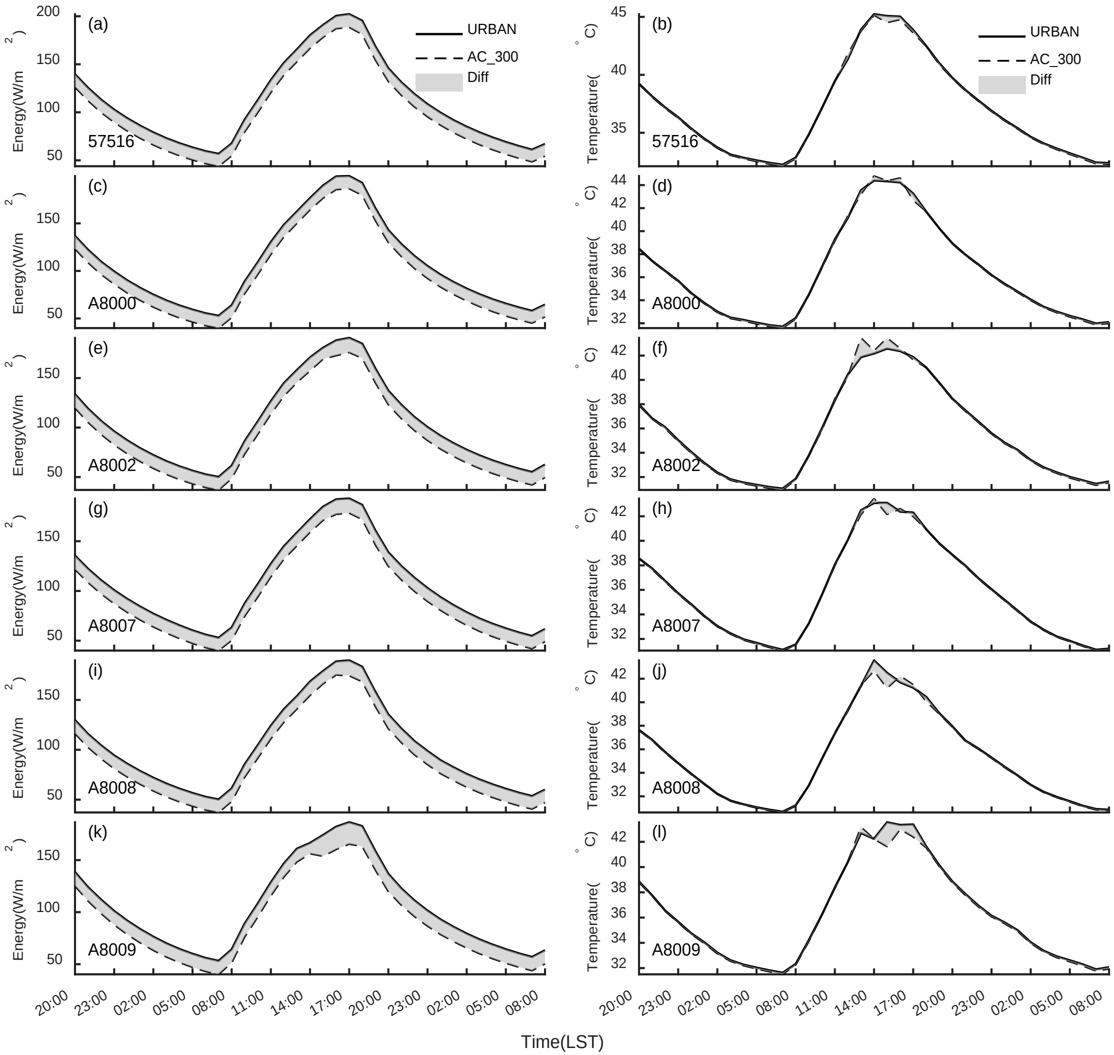
$$T^* = \frac{\Delta t}{Q_B} H_{in}^n + T^n$$

$$H_{out}^n = \begin{cases} 0 & \left|T^* - T_{target}\right| \le \Delta T \\ H_{in}^n - \frac{Q_B}{\Delta t}(T_{target} + \Delta T - T^n) & T^* > T_{target} + \Delta T \\ H_{in}^n - \frac{Q_B}{\Delta t}(T_{target} - \Delta T - T^n) & T^* < T_{target} + \Delta T \end{cases}$$

T_{target}: $298K \longrightarrow 300K$

Station	Sensible heat (%)	Latent heat (%)	AC energy (%)	Total (%)
市区沙坪坝（57516）	11.7	0.00	11.2	11.6
市区新牌坊（A8000）	12.1	0.00	11.6	11.9
市区陈家坪（A8002）	13.0	0.00	12.4	12.6
市区九宫庙（A8007）	12.8	0.00	12.1	12.3
市区佛图关（A8008）	13.2	0.00	12.5	12.8
市区南坪（A8009）	13.7	0.00	13.1	13.3
Average	12.8	0.00	12.2	12.4

Table.2 Compared to URBAN case, reduce percentage of energy released by air conditioner simulated by AC_300

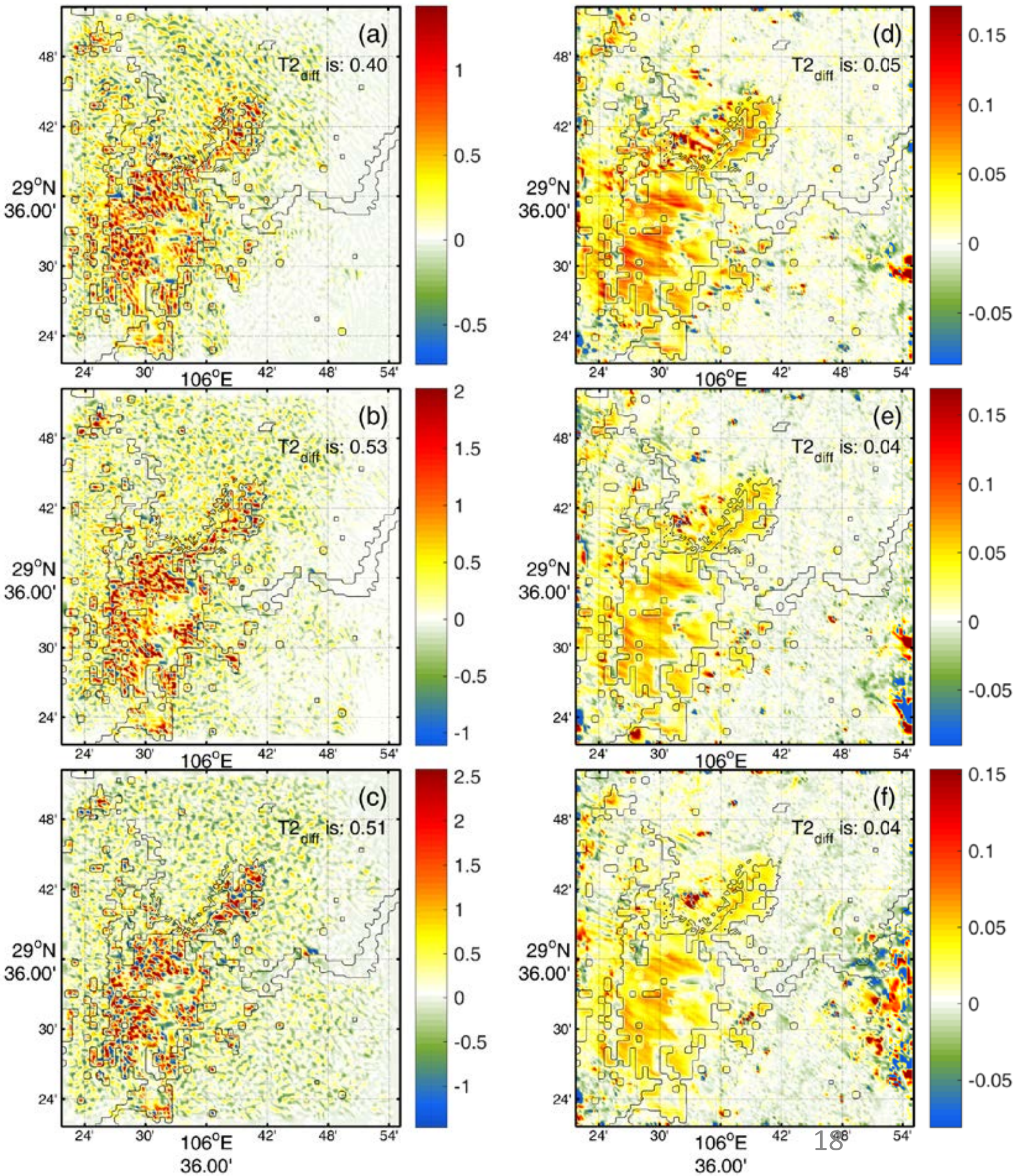


Average anthropogenic heat reduces 10W/m^2;

But small difference in temp.

Fig.12 Energy difference and ambient temperature difference simulated by URBAN and AC_300 case from Aug.15th to Aug.16th

Mitigation effects of cool roof



Default roof reflectiveness is 0.2.

Daytime temp. reduction: ~0.5℃

Nighttime inapparent reduction ~0.1℃ due to reduced heat storage.

Fig. 13 Temperature difference between URBAN & REF_0.8 in different time on Aug.15th

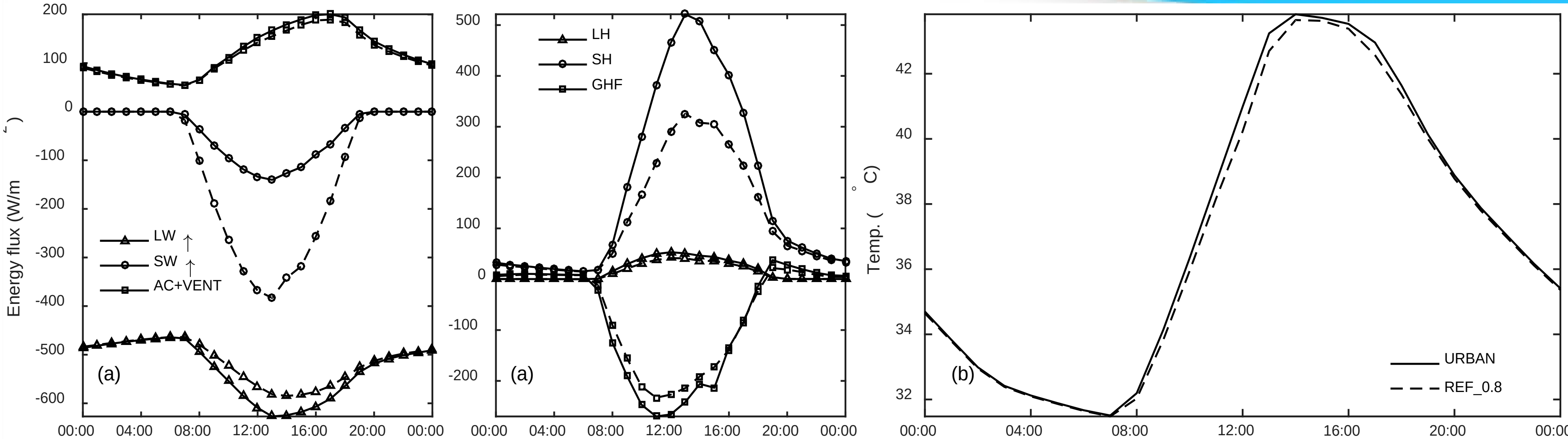


Fig.14 Urban site average energy flux released from ground and 2m temp. simulated by URBAN and REF_0.8 case

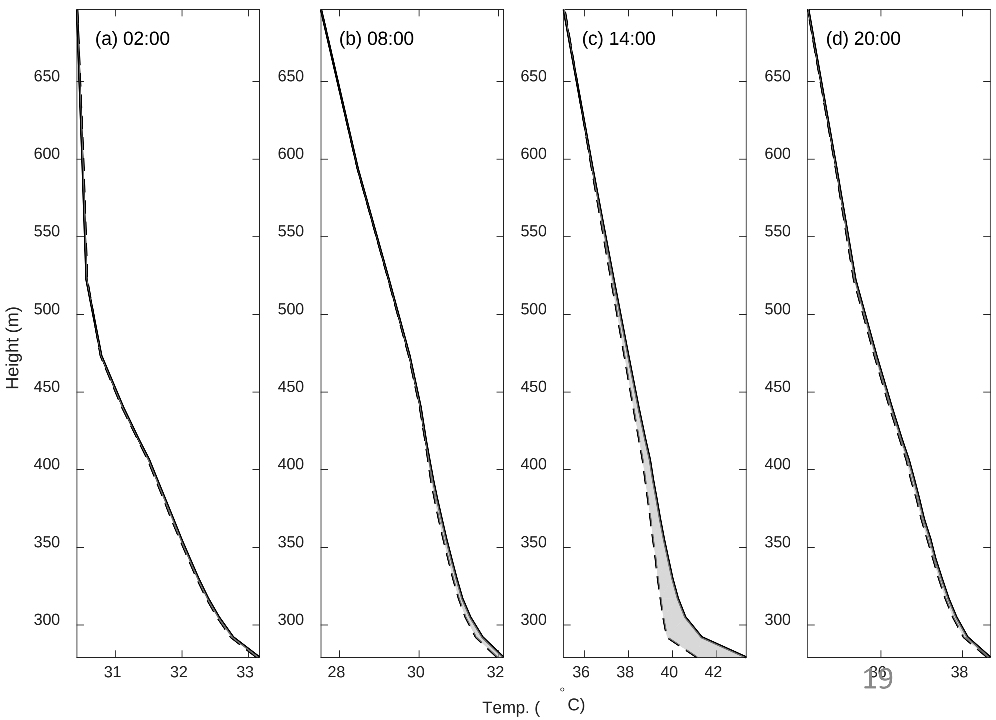
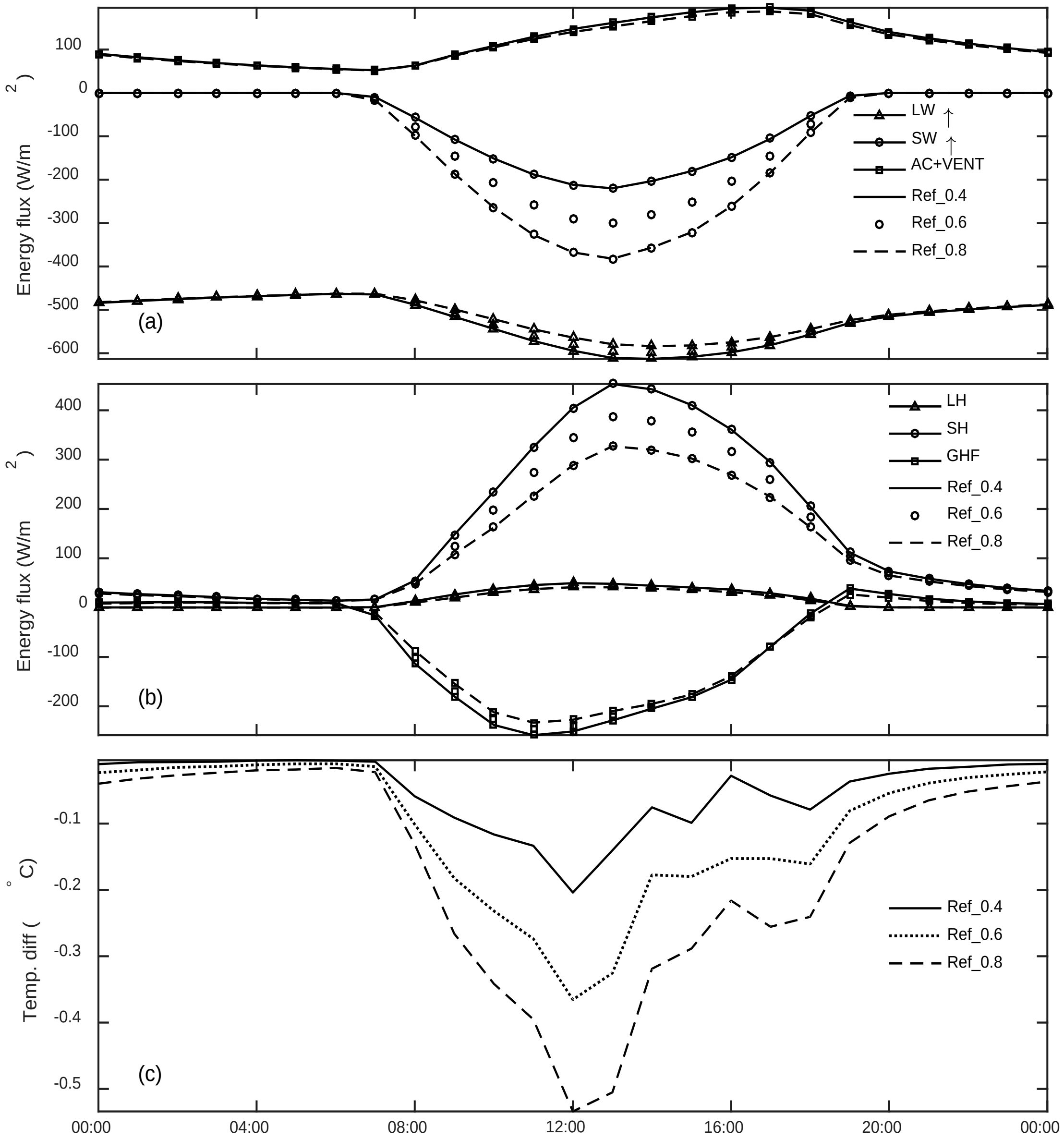


Fig.15 Simulated Temp. profile of urban site Nanping in Aug. 15^{th}



Liner change according to roof reflectiveness.

Fig.16 Average urban energy and 2m Temp. difference from URBAN case under different roof reflective

Review the influence of urban buildings, AC system and roof on air temperature and energy

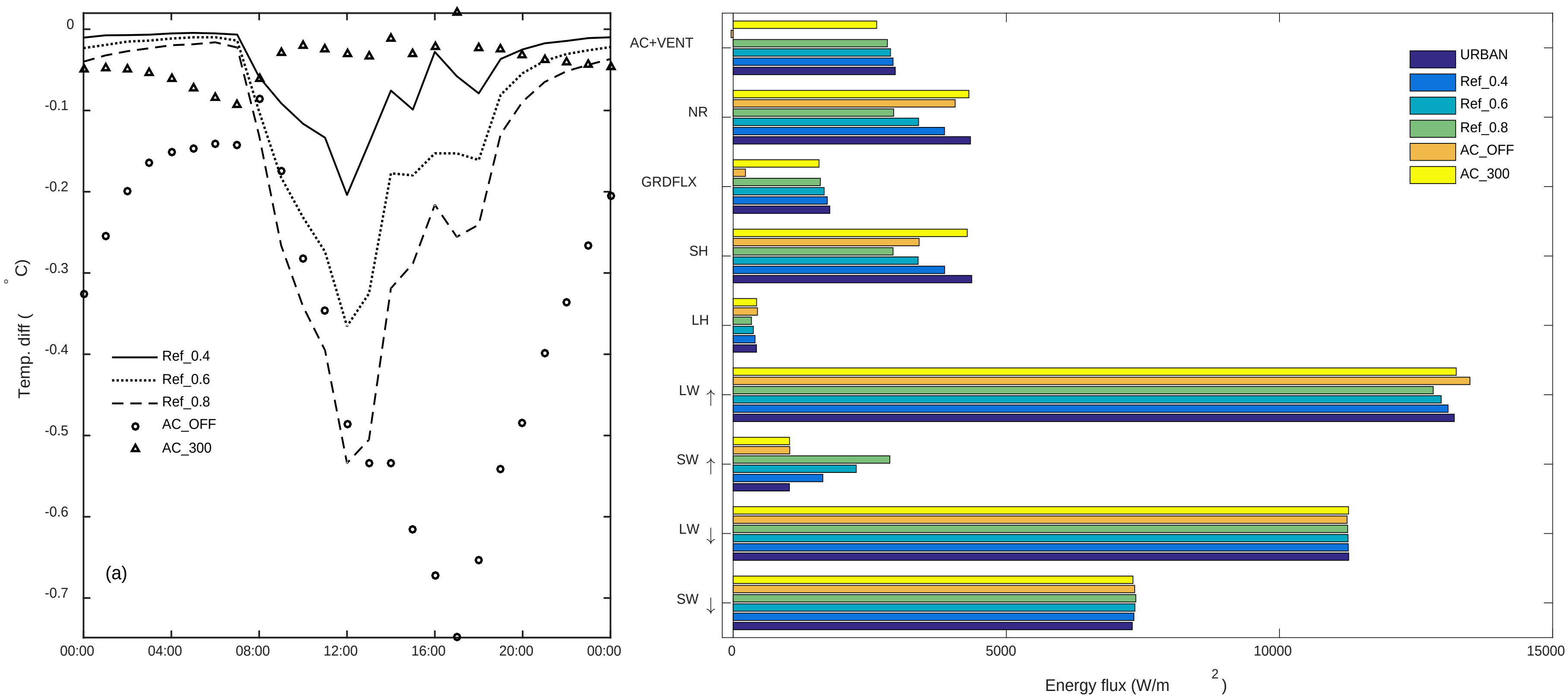


Fig. 17 2m Temp. difference between compared cases and URBAN, and total energy flux of Aug. 15th simulated in all cases

Conclusion

- (1) Chongqing thermal environment can be well reproduced by BEP+BEM scheme.
- (2) Air temperature distribution is affected by both topography and urban surface. Mountains block the outflow from city, let background wind to climb or circle around, contributes to the enhancement of urban heat island.
- (3) Heat released from AC can raise average near-surface air temperature by 0.5°C, and affects vertical temperature of PBL. The change of target temperature of AC have minor effect of air temperature.
- (4) Changing roof reflectiveness from 0.2 to 0.8 can reduce daytime temperature by 0.5°C, and indistinctively reduce nighttime temperature.
- (5) AC_OFF case has the most significant influence on urban air temperature.

Thank you